Chapter 2
Analysis Concepts and Procedures for Interior Areas

2-1. Overview

Study strategy includes procedures, assumptions, and activities associated with the study process. Hydrologic engineering analyses evaluate interior facilities using present planning guidelines. The interior system is analyzed separate from the line-of-protection project analysis. A minimum outlet facility is required to remove water through the levee or floodwall. This "minimum" facility, discussed in later chapters, becomes the starting point from which additional outlet facilities are formulated. Economic and other analyses are performed for several time- and development-related conditions. These are existing conditions and future conditions for with- and without-project features in place (EM 1110-2-1413 and ER 1105-2-100).

2-2. Planning Study Phases

There are two phases of the planning study process (ER 1105-2-100): reconnaissance and feasibility. The preconstruction engineering and design phase follows the planning phases.

a. Reconnaissance phase. The reconnaissance phase is fully funded by the federal government and is normally completed in 12 months. The objectives are to identify the flood problem, determine if there is at least one feasible solution that has a federal interest, identify a local cost-sharing sponsor, and (assuming a possible project) prepare an initial project management plan (IPMP) for the feasibility phase.

b. Feasibility phase. This second phase takes up to 4 years to complete and is cost-shared equally between the federal government and the local sponsor. The objectives of the feasibility phase are to perform detailed investigations and evaluations of a range of alternatives, and recommend a plan to reduce the flood damage potential.

c. Preconstruction engineering and design (PED) phase. The PED phase continues the design efforts of the recommended plan and encompasses the more detailed construction planning and engineering necessary for building the project. Major items are a reevaluation report, design documents, and plans and specifications. For interior area analysis, the key elements of the recommended plan will be reevaluated considering any additional information. If there are no changes, the reevaluation report may be brief. Design documents, usually called design memoranda (DM), are required for key features such as pumping stations and major gravity outlet works. Hydrologic engineering requirements are normally minimal, with emphasis on detailed hydraulic design studies of the major features (USACE 1991).

2-3. Hydrologic Engineering Studies

Hydrologic engineering studies are conducted within the framework of the planning and design processes. The without-project and with-project conditions must be studied and a hydrologic engineering management plan developed.

a. Without-project conditions. The initial step is to develop stage-frequency relationships at key locations for existing without-project conditions. The process is repeated for at least one future time period if conditions affecting hydrology and hydraulics change. The process is critical to establish the magnitude of the flooding problem and to define potential flood damage reduction measures and actions to study. For studies with an existing line-of-protection in place, this hydrologic analysis is for the existing system and facilities. Where a new line-of-protection is to be established, a minimum facility must be evaluated as part of the line-of-protection feature. The hydrologic analysis of the interior area then includes the minimum outlet as the without-project condition.

b. With-project conditions. After the without-project conditions are evaluated, a number of flood damage reduction plans are arrayed and evaluated. Common interior measures include gravity outlets, pumping stations, and detention storage areas. Other measures should also be evaluated, including at least one nonstructural plan (Section 73 of Public Law 93-251), and a flood warning-preparedness program plan that is complete or a component of a comprehensive plan (ER 1105-2-100).

c. Hydrologic engineering management plan (HEMP). The HEMP is a technical outline of the hydrologic/hydraulic studies necessary to successfully formulate a solution to a particular water resource problem. It should be detailed enough to define the study strategy. It is used to establish resource allocations and time and cost estimates. Study resources include personnel, schedules, and funding. Besides being a technical guide, a HEMP is valuable in explaining and justifying to the local sponsor the activities needed for the study and any in-kind service agreements. The HEMP is also used to define the hydrologic engineering requirements for the IPMP. Appendix C provides an example of a HEMP for an interior area.

2-4. Study Setting

Corps studies are normally in urban settings or partially developed areas. For some studies, an analysis of agricultural areas is required. The type and size of the flood damage reduction measures studied and implemented are influenced by the setting.

a. Agricultural areas. Hydrologic engineering analyses for agricultural areas generally involve a single subbasin adjacent to the levee. Volume and duration of flooding are usually more important than peak inflow to the line-of-protection. Seasonal effects are often important due to crop growing patterns and changing damage potential throughout the year. A continuous record analysis is normally used in the analysis.

b. Urban areas. Urban area analyses are usually more complex than agricultural areas. Rainfall-runoff analysis may include multiple subbasins. If natural or detention storage is limited, peak flow may be as important as volume. Layout, design, and operation of existing and potential future storm sewer systems must be considered. Investigations involving trade-offs between pumping capacity and nonstructural measures, such as relocation to gain more ponding area, may be required. The feasibility of flood-warning-preparedness components should be investigated.

2-5. Initial Preparation

Hydrologic engineering requires coordination early on with the study manager and other study team members to clarify the type of study, study objectives, and general scope of the requirements and constraints. Known problems and issues that affect the detail, cost, and conduct of the study should be described. Communication with counterparts are established and maintained. Field reconnaissances are conducted to collect information and insights about the study. The use of previous study data and information should be scrutinized and used to the extent possible.

a. Information needed. The following information typically is needed to develop hydrologic engineering analyses.

(1) Previous study data and reports.

(2) Maps, including USGS quadrangle sheets, topographic maps, aerial photographs, ortho-photographs, zoning plans, storm sewer layouts, etc.

(3) Historic flood events information including storm intensity and distribution patterns, high-water marks, frequency of overtopping, flow patterns, debris and sediment, and response times and actions.

(4) Existing and potential future flood control facilities including design capacities and operation procedures of gravity outlets and pumping stations.

(5) Survey cross-sectional information of major conveyance system.

(6) Future land use projections.

(7) Institutional responsibilities/capabilities.

(8) Regulatory policies affecting development off and on the floodplain.

(9) Identification of environmentally and culturally sensitive areas.

(10) Secondary water effects such as water quality, sediment, debris, and ice, which may affect study procedures and analysis costs.

b. Information sources. The following are common sources of information:

(1) Corps files of previous studies.

(2) Local agencies such as drainage and levee districts, planning commissions, public works departments.

(3) Federal agencies such as USGS, SCS, USBR, FEMA, TVA.

(4) State agencies such as Department of Water Resources, Natural Resources or Conservation.

(5) Railroads, highway departments.

2-6. Relationship Between Interior and Exterior Stage

A detailed description of the relationship between interior and exterior stages is found in EM 1110-2-1413. The following paragraphs summarize that material.

a. Fluctuating water levels both exterior and interior to the line-of-protection make interior area analysis unique. If the exterior and interior occurrences display a consistent relationship with each other, then, to a certain degree, one can be predicted from the other. The interior and exterior events are said to be **correlated**. If the physical and meteorologic processes of the interior and exterior events are related to one another, they are said to be **dependent**. If the interior and exterior events produce stages that coincide, e.g., the interior is high when an exterior event occurs, they are said to be **coincidental**. Coincidence can exist whether or not the interior and exterior occurrences are correlated or dependent.

b. It is possible, though not likely, that there is complete noncoincidence in a study area, e.g., the interior and exterior water levels will never be high or low at the same time. The interior analysis could be performed without consideration of exterior conditions, thus simplifying the analysis. The occurrences could be correlated and either dependent or independent, but it would not affect the analysis.

c. At the other extreme, it is possible that there is complete coincidence, e.g., high exterior levels are always present when an interior event occurs. The occurrences would likely be correlated, although not necessarily dependent, but it would not be important to the analysis approach.

d. The study situation most likely lies between these two extremes. Analyses to determine the degree of correlation may help determine the likelihood of coincidence or independence but are of doubtful value. Correlation studies are most useful for developing a predictive capability. Formal study to determine the degree of independence is not possible now. Lack of correlation can suggest, but not prove, independence. More likely, the degree of dependence is based on inspection of the available record and judgments of the meteorological and physiographic origins of the interior and exterior events. Thus, the critical focus for the analysis must be an assessment of coincidence.

e. Inspection of the historic record is required to determine correlation, independence, and coincidence. Establishing bounds on the consequences of decisions regarding these factors is an important analytical approach. Analysis at the two extremes of assuming complete coincidence and noncoincidence is useful. Also, by determining the relative consequences of independence, judgments regarding its importance to the study can be made. Table 2-1 summarizes hydrologic analysis considerations for various levels of coincidence and dependence of interior and exterior conditions.

2-7. Interior Analysis Computational Methods

Two hydrologic computation methods are normally performed for analyses of interior areas: continuous record simulation, and hypothetical events. Analyses of significant historic events for

Table 2-1
Assessment of Coincidence

COINCIDENCE	DEPENDENCE	EXAMPLE/COMMENTS	ANALYSIS CONSIDERATIONS
(HIGH)	(HIGH)	Hurricanes, large regional events; interior and exterior areas of similar magnitude.	Blocked gravity outlet conditions are common. Conventional hypothetical frequency analyses often appropriate for urban areas.
	(LOW)	Storm season of small interior area coincides with snowmelt runoff of large basins.	Continuous record analysis methods or probabilistic approaches generally required. Gravity outlet is often blocked during interior events.
	(HIGH) (LOW)	This range of coincidence is most common. Relatively high likelihood of interior and exterior events occurring simultaneously.	Continuous record analysis or probabilistic methods generally required. Gravity outlets may be blocked during critical interior events.
	(HIGH)	Timing of interior and exterior events is such that they rarely coincide. May be affected by operation of upstream project.	Considerable study may be required to identify this condition and to assume its existence in the physical process. Coincident hydrology generally appropriate.
(LOW)	(LOW)	Rare condition. Interior flooding rarely if ever coincides with high exterior stages. Studies generally limited to gravity outlet assessments.	Coincident interior analysis is not necessary.

model calibration/validation and system performance are normally required. The methods used depend largely on the study type and setting, resources availability, nature of flooding, available information, and a host of other factors. Most studies require combinations of both approaches.

a. Continuous simulation analysis (CSA) concepts. Continuous simulation methods involve analysis of continuous records of hydrologic events. The procedure consists of performing sequential hydrologic simulation of inflow, outflow, and change in storage to derive interior water surface elevation hydrographs given exterior stages and interior runoff and/or seepage for the entire period-of-record. Figure 2-1 presents a general summary of the concepts involved in the continuous simulation method.

(1) CSA overview. Continuous precipitation data (normally historic rainfall gaged records) are developed for each subbasin. Subbasin loss rates are subtracted and the runoff is transformed to the outlet. Base flow is added to yield continuous runoff hydrographs. Hydrographs are combined and routed through the system to the line-of-protection to yield inflows for the interior ponding area. These data are used with exterior stage data and the characteristics of gravity outlet and pumping stations at the line-of-protection to simulate the operation of the system. The results are continuous stage hydrographs at the interior ponding area. Subsequently, interior stage-frequency relationships can be derived.

(2) CSA applicability and limitations.

(a) Continuous simulation is attractive because it preserves the seasonality, persistence, and coincidence or noncoincidence of exterior river stages and interior flooding. The method enables project performance to be displayed. It is easily understood by the other study participants, the local sponsor, and the general public. Most importantly, the issue of coincidence of flooding is addressed inherently in the analysis. The analysis is particularly relevant for evaluating agricultural damage.

(b) Two major considerations in continuous simulation application are the length-of-record and the amount of data required for the analysis. The record of data may be unrepresentative (records are often too short), resulting in an inappropriate size and mix of measures and operation specifications of the system. Continuous simulation procedures require a significant amount of information and possibly extensive calibration and extrapolation.

b. Hypothetical event analysis (HEA) concepts. HEA uses single historic or synthetic events to develop frequency-based estimates of flow and/or stage.

(1) Hypothetical analysis for dependent events. This procedure is applicable when interior and exterior floods are dependent for the same meteorologic events. A single series of storm events is assumed to occur over both the interior and exterior areas. A constant exterior stage, "blocked" or "unblocked" exterior conditions may be evaluated using a series of hypothetical storm events on the interior area to evaluate the two bounds. These conditions represent total coincidence and noncoincidence, respectively. Figure 2-2 graphically depicts the concepts for dependent events. Event precipitation data, subbasin loss rates, and runoff transforms are used to compute the runoff hydrograph. Base flow is added to yield the total subbasin hydrograph at the outlet. This is called the unit hydrograph procedure and it is described in detail in EM 1110-2-1417. Hydrographs are combined and routed through the system to yield an inflow hydrograph for the interior area. These data are used with exterior stage data for the same flood event to simulate the expected operation of the system. Exterior

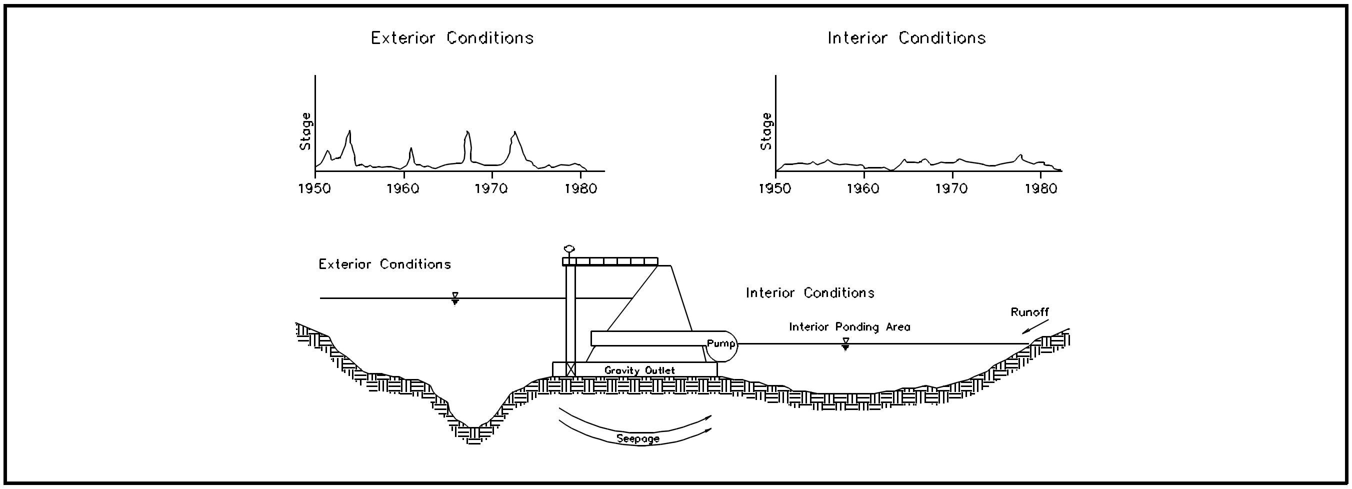

Figure 2-1. Continuous simulation analysis concepts

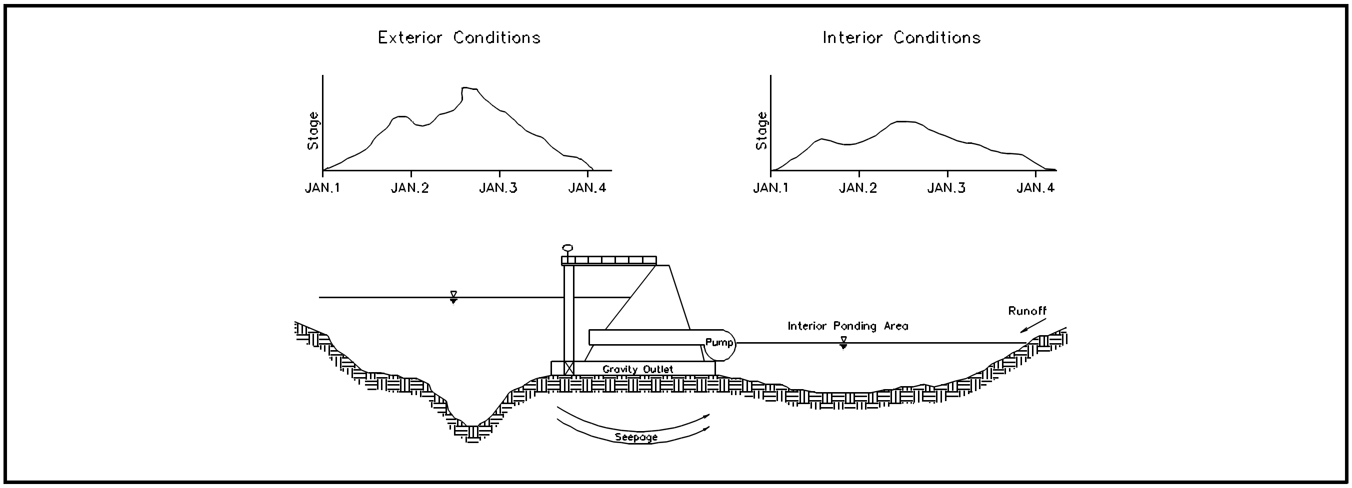

Figure 2-2. HEA concepts for dependent events

discharge hydrographs are computed using the same method described for the interior discharge hydrographs. The exterior stage hydrograph is then defined by applying the exterior discharge hydrograph to a rating curve at the interior ponding area primary outlet.

(2) Hypothetical analysis for independent events. This procedure is applicable when floods affecting the interior area can be independent of floods that affect the exterior stages. These areas are often relatively small interior areas located along large rivers, lakes, or coastlines. One probabilistic procedure applicable to the analysis of independent events using hypothetical rainfall is the coincident frequency method, conceptualized in Figure 2-3. This method applies the total probability theorem to generate stage-frequency functions for interior areas affected by various combinations of interior and exterior flooding. Figure 2-4 defines the steps necessary to perform the coincident frequency procedure.

(3) HEA applicability and limitations. HEA requires less data than the continuous record technique. The analysis generates hypothetical frequency hydrographs in which the peak flow rate, runoff volume, and all durations are assumed to be statistically consistent with the percent chance exceedance assignment of the rainfall events. This method overcomes the potential lack of data problems of CSA. However, for many study settings, interior and exterior flooding are not totally dependent or independent.

c. Using both CSA and HEA. Often continuous record data are available, but the number of years of record is short. Short historic records may be unrepresentative with respect to giving good estimates of more rare events or combinations of events. Thus, 30 to 40 years of record may be inadequate to derive stage-frequency results for rare events (1- to 0.2-percent events). For this situation, the CSA method should be used to define the more frequent events and the HEA method to help determine the rarer events. The resulting frequency relationship may be a product of both approaches.

2-8. Summary

Hydrologic analysis techniques used in planning studies of interior areas vary in analytical concepts and procedures. Unfortunately, the analysis is usually tedious and complex. Selection of techniques should be based on the type and phase of the study; complexity and relative importance of the coincident nature of flooding at the outlet; complexity of the hydrologic system; the nature of the flood damage, environmental, and social factors pertinent to the study area; and the experience of the analyst. The two techniques presented here are the continuous simulation approach and the hypothetical event approach; several variations exist with each. When working on a study, one should try to use everything available from both methods. For example, the CSA may be the best method to use on a particular study; however, the continuous record precipitation is so short that an HEA analysis is needed to include the larger, rarer events. To get the minimum and maximum range of interior stages, an analysis of both totally blocked and unblocked conditions is also recommended.

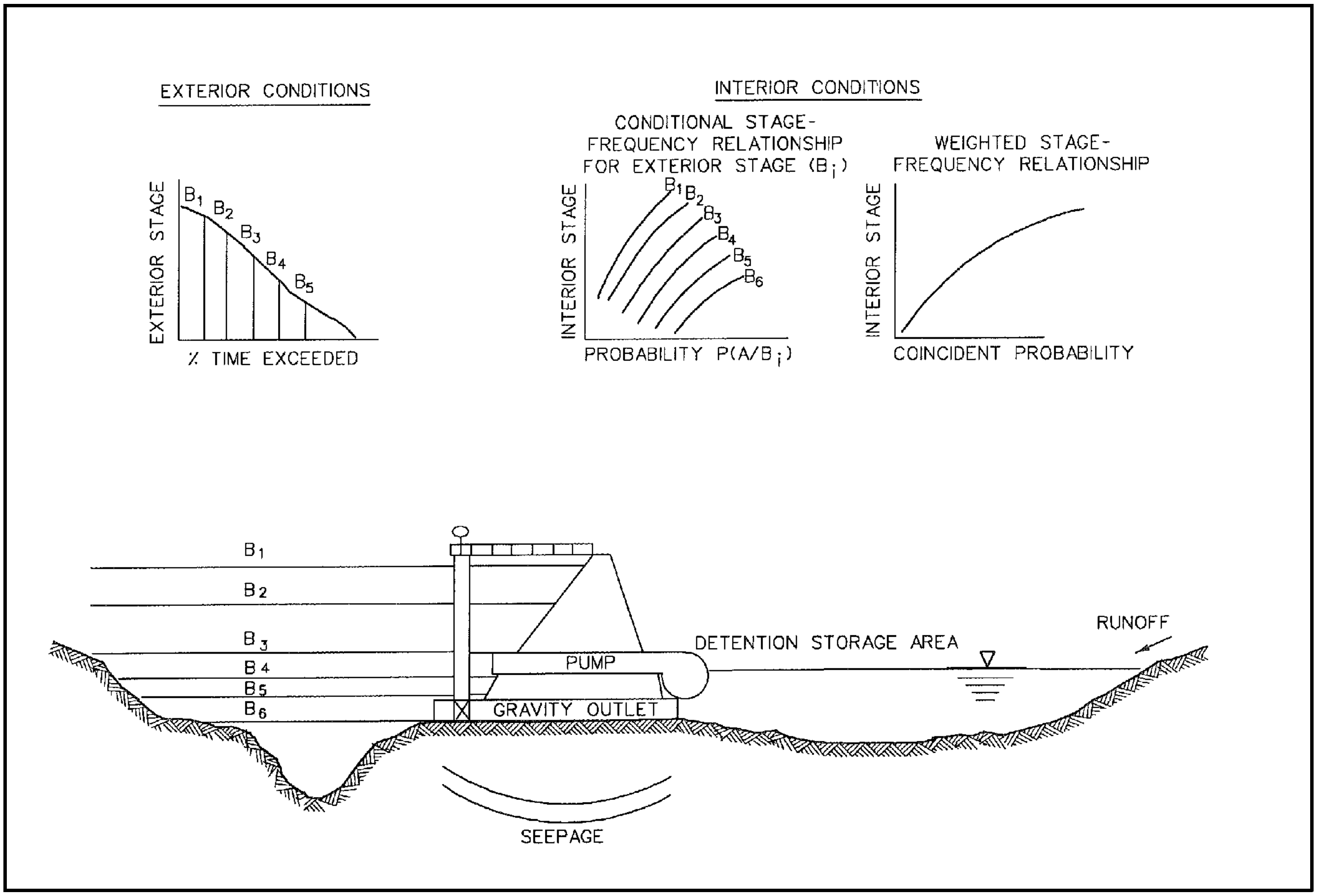

Figure 2-3. Coincident frequency analysis concepts

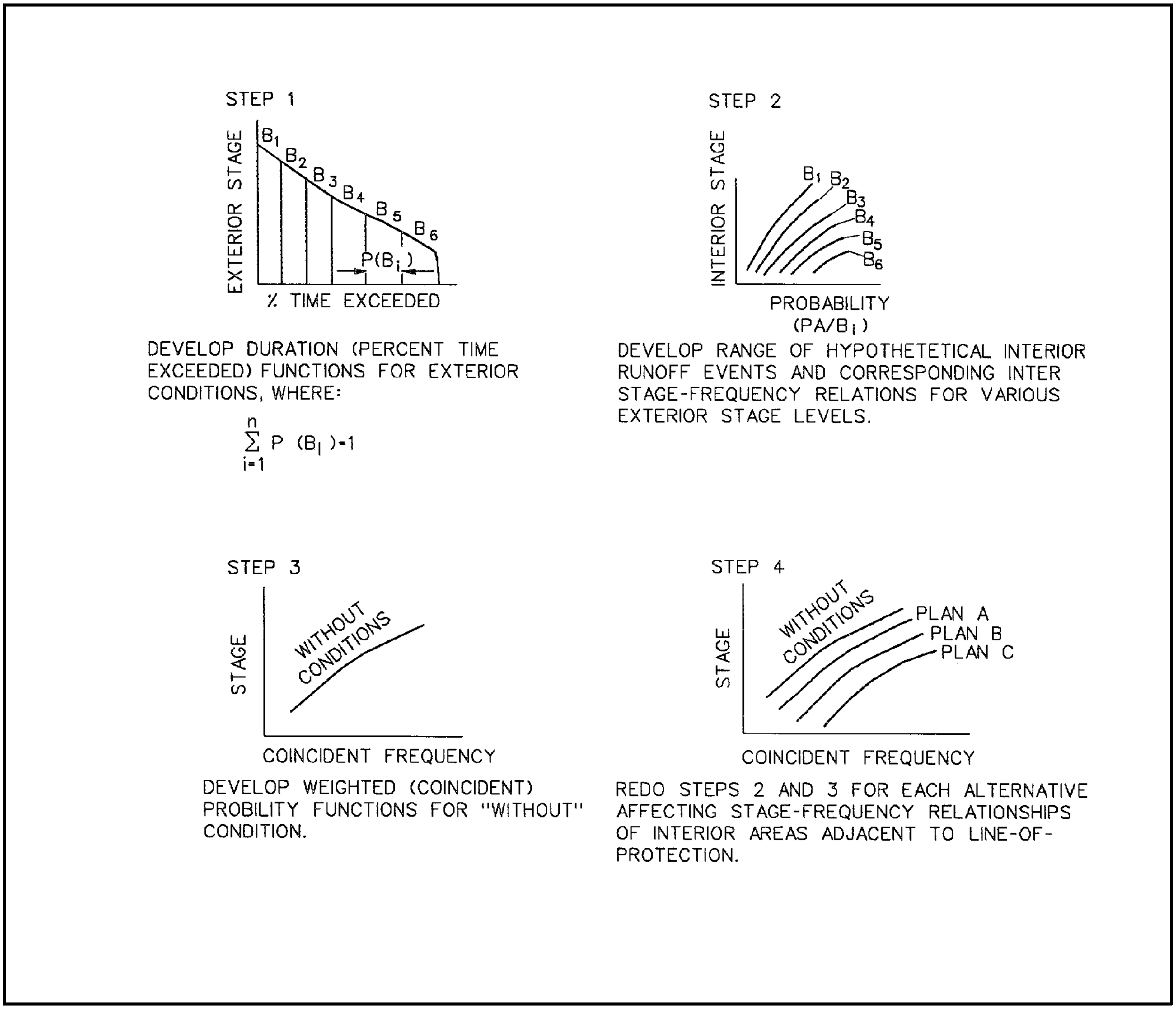

Figure 2-4. Coincident frequency procedures